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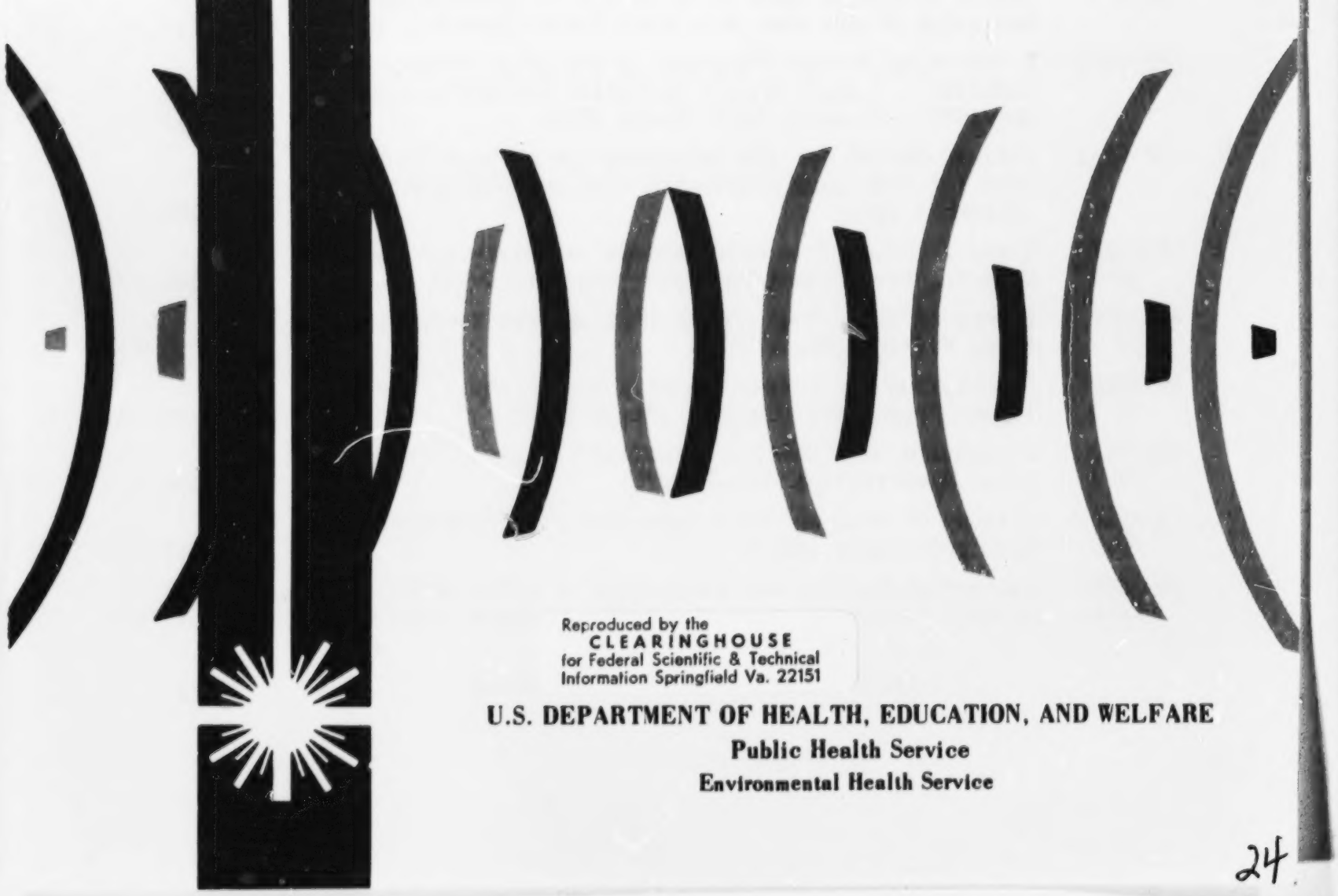
EVALUATION OF AN X-RADIATION DOSIMETRY SERVICE FOR HOME TELEVISION RECEIVERS



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BRH/DEP 70-21

EVALUATION OF AN X-RADIATION DOSIMETRY SERVICE FOR HOME TELEVISION RECEIVERS

Charles P. Warr

Radiation Measurements and Calibration Branch
Division of Electronic Products

August 1970

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Radiological Health
Rockville, Maryland 20852

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FOREWORD

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Within the Bureau, the Division of Electronic Products (1) develops and administers performance standards for radiation emissions from electronic products, (2) studies and evaluates emissions of and conditions of exposure to electronic product radiation and intense magnetic fields, (3) conducts or supports research, training, development, and inspections to control and minimize such hazards, and (4) tests and evaluates the effectiveness of procedures and techniques for minimizing such exposures.

The Bureau publishes its findings in Radiological Health Data and Reports (a monthly publication), Public Health Service numbered reports, appropriate scientific journals, and technical report series for the Bureau's divisions, offices, and laboratories.

The technical reports of the Division of Electronic Products (DEP) allow comprehensive and rapid publishing of the results of intramural and contractor projects. The reports are distributed to State and local radiological Health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the Clearinghouse for Federal Scientific and Technical Information.

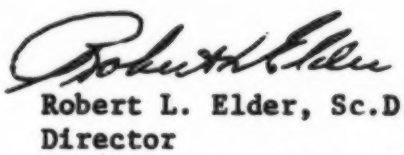
I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

As a part of its responsibility under the "Radiation Control for Health and Safety Act of 1968" (Public Law 90-602), the Division of Electronic Products, Bureau of Radiological Health, carries on a program to evaluate the effectiveness of procedures and techniques for minimizing exposure to electronic product radiation. The present report evaluates the effectiveness of an x-radiation dosimetry service, Ray-Alert, designed to detect x-radiation emissions escaping from the faceplate of television receivers.

As the reporting features of the Ray-Alert service are somewhat different in format from those of conventional dosimetry services designed for radiation workers, a detailed statistical analysis of calibration and test procedures was performed. The statements made in conclusion on the effectiveness of the Ray-Alert system refer to this analysis.



Robert L. Elder, Sc.D.
Director
Division of Electronic Products

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ABSTRACT

An analysis and evaluation of the consumer oriented, television x-radiation dosimetry system, Ray-Alert, was performed. Detailed attention was given to statistical analysis in order to specify the test conditions as rigidly as possible. The results are summarized, taking into account the capability of the dosimetry service and its application to the measurement of x radiation from television receivers.

ACKNOWLEDGEMENT

The author would like to acknowledge Messrs. Paul S. Ruggera and Marshall I. Pomer of the Division of Electronic Products for their aid in high-voltage circuit analysis and computerized statistical analysis respectively.

EVALUATION OF AN X-RADIATION DOSIMETRY SERVICE FOR HOME TELEVISION RECEIVERS

INTRODUCTION

A dosimetry device and service, the Ray-Alert, was offered to the public through retail outlets in January of 1969.[1] The device, manufactured by the Advanced Research Corporation, 5100 Wisconsin Avenue, N.W., Washington, D.C., is designed to detect x radiation emitted from television picture tubes (CRTs). It consists of a containing chamber of low average atomic number plastic[2] loaded with a 3 by 3 by 0.9 mm "chip" of thermoluminescent material, CaF_2 (Mn), in a small pocket beneath an access plate. This chamber is configured as an equilateral spherical triangle with thickness and side lengths of approximately 3 mm and 6 cm respectively. Three attachable mounting members of the same plastic material are provided which, when fixed to the surface of the CRT by means of small adhesive pads (also supplied), cantilever the chamber approximately 5 cm above the CRT surface. The material of the chamber and its mounting members is bright red in color throughout, and the top of the chamber carries a circular decal, approximately 2 cm in diameter, showing a red and yellow trefoil pattern (fig. 1). Although this pattern is not precisely the same in geometrical detail and color as that specified for radiation warning symbols[3], it does give much the same impression. The user is instructed to fix the device at the center of his television picture tube faceplate by means of the mounting arrangement provided, and expose it for a period of 10 hours. A total exposure of 5 mR would thus correspond to an average exposure rate of 0.5 mR/hr. Subsequent to exposure, the device is mailed to Santa Fe, New Mexico, where the thermoluminescent material is removed and interpreted in terms of exposure by the Eberline Instrument Company. The resultant exposure figures are reported to the Advanced Research Corporation, which then issues a report to the user.

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[1] Statement by Charles C. Johnson, Jr., Administrator, Environmental Health Service, formerly the Consumer Protection and Environmental Health Service, May 14, 1969.

[2] Levine, H., Division of Electronic Products, Bureau of Radiological Health. Unpublished report (April 2, 1969).

[3] See 10 CFR 20.203.

Figure 1. Ray-Alert device.

This report describes a test of the Ray-Alert device and service as conducted by the Radiation Measurements and Calibration Branch of the Division of Electronic Products, Bureau of Radiological Health. As the service is intended for use with television receivers in the home, the test was designed to conform (under well-defined conditions of x-radiation exposure and receiver operating parameters) to the instructions issued by Advanced Research Corporation for use in the home.

EXPERIMENTAL PROCEDURE

Sixty-one Ray-Alert devices were acquired from a retail outlet for the test. Each was labeled with a detachable number and stored in a shielded counting vault until needed.

Because the reporting technique of the service was designed to supply a categorical exposure response ("satisfactory" is less than 0.4 mR/hr; "marginal" is greater than 0.4 mR/hr and less than 0.6 mR/hr; "excessive" is greater than 0.6 mR/hr) rather than a numerical one in terms of x-radiation exposure, it was decided to expose the test devices in groups. The exposure to each group was chosen so that several groups of devices would fall into each of the three response categories of the service.

The groups of devices, with the exception of a control group, were irradiated by x radiation of an appropriate nature at various well-determined exposure levels and were then submitted individually through the routine reporting channel of the Ray-Alert service to the Advanced Research Corporation. The test devices were not identified as such, and the Advanced Research Corporation was not notified that a test was to be conducted.

CALIBRATION AND EXPOSURE

Two calibration techniques were used. In order to facilitate setting the exposure rate at approximately the correct level, a Victoreen 208A ion chamber was used with a Victoreen Minometer II for readout. Prior to use, the chamber was calibrated against a free-air ionization chamber and a correction factor obtained at an energy distribution (not shown) approximating that to be used in the experiment. Figure 2 shows the x-radiation energy distribution used in the experiment. The x-ray tube used for these calibration exposures was operated at 30 kVcp. It had an inherent filtration of 0.31 mm Al, and was used with 11.1 mm Al added filtration.

To calculate the exposure rate more exactly for each exposure group, an integrated value of exposure at the exposure site was needed. $CaF_2(Mn)$ thermoluminescent dosimeters (TLDs) were chosen, four to be exposed with each of the eight exposure groups and six to be retained in a control group, because of their sensitivity in the x-radiation energy region of interest, their low sensitivity to natural background,

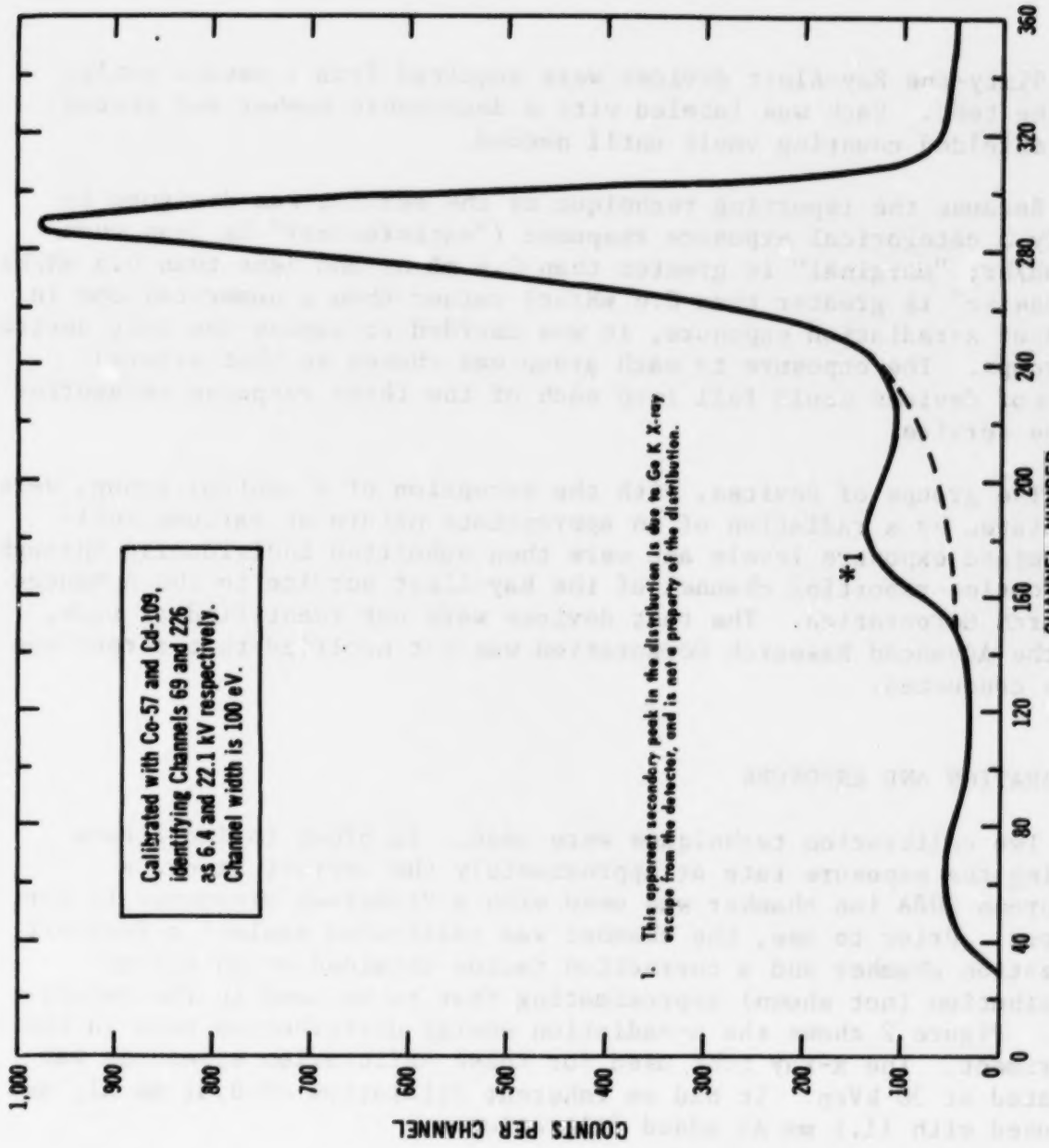

Figure 2. CRT x-radiation distribution.

and their small size with respect to the cross-sectional area of the x-radiation field. Twelve of the 50 dosimeters used were calibrated against a free-air ion chamber (see table 1), and a factor, $\bar{F} = 1.45$ (see table 3 for a summary of calibration statistics), was calculated to convert TLD reader "counts" to exposure in units of μR. As a check of the possible dependence of dosimeter response on exposure level, a calculation of the factor $\bar{F}_g$ (see table 1) was made for each of the four calibration exposure groups as well as for the aggregate, $\bar{F}$, of 12 data points. No systematic relation was observed with respect to exposure level between the four group conversion factors. The values of these factors were distributed about the value of the aggregate factor, $\bar{F}$, and differed from this factor by no more than 2.1 percent. Figure 3 shows the high degree of linearity between TLD response and free-air ion chamber measurements.

The sample variances for each of the four calibration exposure groups were observed to differ. Calculations were made to determine if this variability was nevertheless compatible with the assumption of equal variance for each group. Acceptance of this assumption would support the testing of group F means to show that they did not differ significantly from $\bar{F}$, and would support the assumption that F is independent of exposure level. Using Bartlett's Test[4] for homogeneity of variances, the "F ratio" statistic[5] was found to be 0.4849 with 3 and 115.2 degrees of freedom.[6] This implied that the assumption of homogeneous variance would be accepted at the 5 percent level of significance. In fact, at least as much variability in the sample variances as was observed would be expected to occur about 70 percent of the time. The aggregate factor, $\bar{F}$, was therefore taken as the conversion factor for dosimeters 13 through 50 (see table 2) without further reservation.

A conventional color television CRT and chassis were used as a source of x radiation for the exposure groups. Certain modifications were made, however, to ensure beam uniformity and precise kilovoltage control. The spectral distribution of the x radiation at an anode potential of 30 kVcp was determined using a Ge(Li) spectrometer with a resolution at 14.4 keV of approximately 450 eV(FWHM). This particular anode potential was chosen as reasonably representative of anode voltages in television receivers found to be emitting x radiation. Accurate (better than 1 part in 10,000) high-voltage power supplies and measurement devices were available for such a potential, and x radiation was produced at a rate

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[4] Dixon, W.J. and F.J. Massey. Introduction to Statistical Analysis. Second Edition, McGraw-Hill, New York, N.Y., pp. 179-180. (1957).

[5] Not to be confused with the conversion factor, F, used to convert TLD "counts" to units of exposure in μR.

[6] Dixon and Massey, op. cit., p. 402.

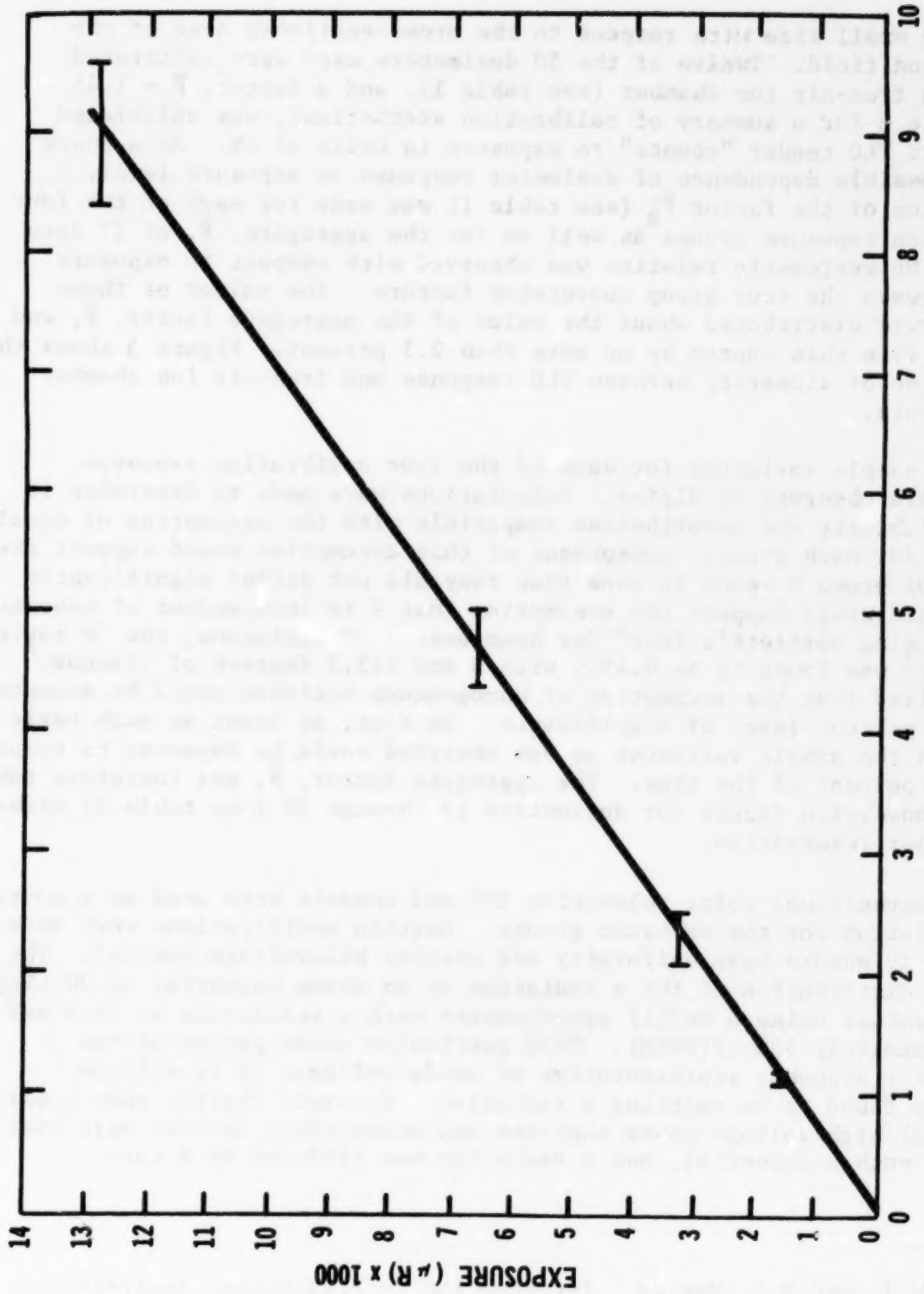

Figure 3. Free-air ionization chamber exposure and net TLD counts.

Table 1. TLD calibration data and statistics.

Dosimeter	F.A.I.C. exposure[a,b] (μR)	Counts[c]	Net Counts[d]	Conversion factor F_i (μR/count)	Group mean $\bar{F}_g$ (μR/count)	Group sample variance s_g^2	Group standard error S_g	$\frac{S_g}{\bar{F}_g}$ (% $\bar{F}_g$)
1		1317	1143	1.46				
2	1670	1304	1130	1.48	1.48	0.0004	±0.0115	±0.78
3		1291	1117	1.50				
4		2488	2314	1.44				
5	3330	2555	2381	1.40	1.45	0.00310	±0.0321	±2.21
6		2378	2204	1.51				
7		4845	4671	1.44				
8	6710	4802	4628	1.45	1.43	0.0007	±0.0153	±1.07
9		4956	4782	1.40				
10		9011	8837	1.48				
11	13040	9049	8875	1.47	1.45	0.00145	±0.0220	±1.52
12		9399	9225	1.41				

[a]F.A.I.C.=free-air ionization chamber.

[b]Filtration, 0.31 mm Al inherent + 11.1 mm Al added, and kilovoltage, 30 kVcp, were adjusted to simulate the energy distribution of the x radiation from the particular television CRT used.

[c]Preheat time is 6 seconds at 147° C; integration time is 15 seconds at 250° C; 150 picoamperes of photomultiplier current is approximately 1 count per second.

[d]Background is taken from controls numbered 45 through 50 (see table 2) and from an extrapolation to zero exposure of calibration dosimeters 1 through 12 above by least squares fit.

Table 2. True and reported exposure data.

Dosimeter no.	Exposure group no.[a]	Counts[b]	Net counts[c]	Exposure[a,d] (μR)	Confidence interval 99%	Ray Alert no.	Expected report[e]	Report received
13		1452	1370	1987		4		S
14		1425	1343	1947		5		-f
15	2	1556	1474	2137	±46	6	S	S
16		1386	1304	1891		7		S
17		2448	2366	3431		8		S
						9		M
18		2410	2328	3376		10		S
	3				±79	11	S	M
19		2747	2665	3864		12		S
						13		M
20		2014	1932	2801		14		M
						15		S
21		3118	3036	3621[g]		16		S
						17		M
22		2438	2356	3416		18		M
	4				±83	19	S	M
23		2570	2488	3608		20		S
						21		S
24		2729	2647	3838		22		M
						23		S
25		3422	3340	4843		24		M
						25		M
26		3197	3115	4517		26		S
	5				±111	27	M	M
27		3492	3410	4944		28		E
						29		M
28		3350	3268	4739		30		M
						31		E
29		3272	3190	4626		32		M
						33		M
30		3043	2961	4293		34		M
	6				±106	35	M	E
31		3416	3334	4834		36		M
						37		M
32		3231	3149	4566		38		M
						39		M

Table 2. True and reported exposure data.(continued)

Dosimeter no.	Exposure group no[a]	Counts[b]	Net counts[c]	Exposure[a,d] (μR)	Confidence interval 99%	Ray Alert no.	Expected report[e]	Report received
33		4140	4058	<u>5884</u>		40		E
						41		M
34		4343	4261	6178		42		E
	7				±133	43	M	E
35		4698	4616	6693		44	or	M
						45	E	M
36		4265	4183	6065		46		E
						47		E
37		4130	4048	<u>5870</u>		48		E
						49		E
38		4046	3964	5748		50		M
	8				±134	51	M	E
39		4912	4830	7004		52	or	E
						53	E	M
40		3821	3739	5422		54		M
						55		M
41		5252	5170	<u>7496</u>		56		E
42		5178	5096	7389		57		E
	9				±172		E	
43		5887	5805	8417		58		E
44		5784	5702	8268		59		E
45		84	-	-		00		S
46		79	-	-		0		S
47		81	-	-		1		S
	1			-			S	
48		83	-	-		2		S
49		80	-	-		3		S
50		85	-	-		-		-

[a]Placement of TLD's within each exposure group is respectively: center, right, lower, and left. The center TLD is selected to represent the exposure group and is underlined.
[b]Counts are from the Eberline Model TLR-5 Reader; one count per second represents approximately 150 picoamperes of photomultiplier tube current.
[c]Less background of 82 counts taken from controls numbered 45-50.
[d]Using $\bar{F}$ as given in table 3 to convert from net counts to μR.
[e]S = satisfactory; M = marginal; E = excessive.
[f]No report was received for Ray-Alert No. 5.

Table 3. Calibration statistics summary.

Quantity	Symbol	Value	Units
Sample conversion factor	F_i	See table 1	μR/count
Mean conversion factor	$\bar{F}$	1.45	μR/count
Group mean conversion factor	$\bar{F}_g$	See table 1	μR/count
F sample variance	s_F^2	0.0152	$\mu R/count^2$
Standard error of $\bar{F}$	$S_{\bar{F}}$	0.0104	μR/count
$S_{\bar{F}}$ expressed as percent of $\bar{F}$	S_p	0.74	percent
Population mean of F		---	μR/count
Degrees of freedom	df	11	---
Significance level	α	0.01	---
Number of sample observations	n	12	---
Percentile of the t distribution with α probability and df degrees of freedom	$t_{\alpha,df}$	3.106	---
99% confidence interval about population mean[a]	CI(γ)	1.45 ± 0.0332	μR/count
99% confidence interval about population mean expressed as percent of $\bar{F}$	CI(γ)	1.45 ± 2.29	μR/count, percent

[a]99 percent of the limits so constructed will include the population mean.

sufficient for accurate exposure determinations. The resulting energy distribution is shown in figure 2, with a most probable photon energy of approximately 28 keV and a total energy range of approximately 23 to 30 keV.

The Ray-Alert devices were mounted as prescribed in the Advanced Research Corporation literature enclosed with each device. For each exposure group they were arrayed within a circular area centered on the CRT faceplate of the source. The number of each device determined its approximate location in this circle; the Ray-Alert with the lowest number in its exposure group was positioned at the center of the circle, that with the next highest number at "noon", and the remaining devices at equal distances clockwise around the circle from "noon". The mounting procedure had the effect of placing the bottom of each device approximately 5 cm from the CRT. TLD calibration devices contained in low atomic number plastic capsules (the casings of the Ray-Alert devices had been analyzed and determined to be molded of low atomic number plastic) were suspended between the Ray-Alert devices at an equal distance (5 cm) from the faceplate. For a given exposure group the TLD devices were positioned in ascending numerical order at the center, "noon", "four o'clock", and "eight o'clock" respectively. The exposed TLD devices were then "read", and the resulting data listed in table 2. The exposed Ray-Alert devices and their respective identification cards were enclosed according to directions and mailed in the individual envelopes supplied by the Advanced Research Corporation for that purpose.

DOSIMETRY SERVICE REPORTING

For the 61 Ray-Alert devices exposed and mailed, a total of 60 reports was received (see table 2). The response time from date of mailing to date of receipt of report was noted to be as much as a month. A delay period of this length between exposure and readout would, with many materials, require that the result be corrected for background exposure received during the delay. $CaF_2(Mn)$, however, is relatively insensitive to background radiation with the usual energy distribution. Under the circumstances, therefore, the absence of such a correction does not misrepresent original exposures significantly. No report was received for Ray-Alert #5, and this data point will subsequently not be considered part of the sample for purposes of performance analysis.

As expected during preliminary testing, confidence interval analysis has significantly reduced the number of reports originally interpreted to be "wrong". When the accuracy of the test procedure was taken into account, fewer reports fell into the nominally "wrong" category.

ANALYSIS

The central TLD for each exposure group value (underlined in table 2) was used to calculate the actual exposure of the Ray-Alert devices in that group during irradiation. The other three TLDs of a given exposure group were used to determine whether the central TLD was defective. For exposure group 4, the central reading (TLD #21) was not validated and has been replaced by the average value from the remaining three TLDs (see table 2).

Various measures were taken to ensure a uniform x-radiation exposure rate across the area of the CRT faceplate used for the Ray-Alert exposures. To check the subsequent assumption of x-radiation beam homogeneity, an analysis of variance was performed to determine whether there were significant systematic differences in x-radiation exposure between TLD dosimeter location sites. More specifically, a table was set up arranging the TLD readings in columns by CRT location and in rows by exposure group. The sample mean was then compared to each of the four column means using an "F ratio" statistic with 3 degrees of freedom in the numerator and 21 degrees of freedom in the denominator. This analysis failed to reject the hypothesis of beam homogeneity at a significance level[7] of $\alpha = 0.01$.

Using the data presented in table 1 for TLD exposure calibration, the standard error $S_{\bar{F}}$ of the sample mean was calculated to be 0.0104, or 0.74 percent of $\bar{F}$. To obtain the desired 99 per cent confidence interval for $\bar{F}$, the following expression was used with the assumption that the sampling distribution of F conforms to a t distribution:

$$CI\ (\gamma) = \bar{F} \pm t_{\alpha,df}\ S_{\bar{F}}$$

where γ is the population mean of F, $\bar{F}$ is the sample mean of F, $t_{\alpha,df}$ is a percentile[8] of the t distribution at α significance level and df degrees of freedom, and $S_{\bar{F}}$ is the standard error of the sample mean $\bar{F}$.

Thus we obtain:

$$CI\ (\gamma) = 1.45 \pm 3.106\ \sqrt{0.00127/12}$$
$$= 1.45 \pm 0.0332$$

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[7] Dixon and Massey, op. cit., pp. 90-91.

[8] Dixon and Massey, op. cit., p. 384, table A-5, "Percentiles of the t Distribution."

For 99 percent of the limits so constructed, the population mean will lie within $\pm$ 0.0332 ($\pm$2.29 percent) of the sample mean. It is this confidence interval which is applied in the conversion of the value (underlined in table 2) of the central TLD from counts to μR, and thus it is this confidence interval (expressed in percent of $\bar{F}$) which determines the exposure confidence intervals listed in table 2.

INTERPRETATION AND SUMMATION

Of the 60 Ray-Alert reports received, 48 (80 percent) are considered to be within the confidence interval given in the preceding section, and 12 (20 percent) are considered outside this interval. One report in the group outside the confidence interval was given in a "nonconservative" direction (that is, a "satisfactory" report was given when a "marginal" report should have been issued to correspond to the x radiation given). No reporting errors were made across more than one category boundary.

Considering the substantial number of reports falling within the given exposure confidence intervals, and particularly in view of the conservative bias of those reports falling outside this interval, the Ray-Alert service is largely successful in its goal of detecting and categorizing the approximate level of x radiation from television CRTs at exposure rates near the HEW regulation value[9] of 0.5 mR/hr. As the instructions accompanying the device specifically disclaim its application to comprehensive x-radiation surveys of entire television receivers, such an application was not considered in this report. The relationship between monochrome-color and the probability of x-radiation emissions is not discussed in the Ray-Alert "instructions" and is likewise not considered in this report.

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[9]Regulated under Public Law 90-602.

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